

(12)

**EUROPEAN PATENT APPLICATION**

(21) Application number: 85400145.0

(51) Int. Cl.<sup>4</sup>: **G 01 B 7/00**  
**A 61 B 5/10**

(22) Date of filing: 29.01.85

(30) Priority: 17.02.84 US 581432

(43) Date of publication of application:  
25.09.85 Bulletin 85/39

(84) Designated Contracting States:  
AT BE CH DE FR GB IT LI LU NL SE

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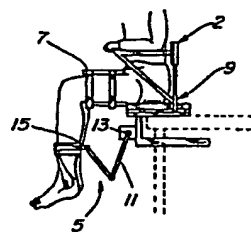
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(54) Knee laxity evaluator and motion module/digitizer arrangement.

(57) The invention relates to a knee laxity evaluator which consists of an instrumented seat (9), a restraint means (7) for restraining the thigh of a patient to the instrumented seat, a motion module (11) for measuring motion of the unrestrained part of the leg relative to the thigh of the patient, and processor means for analyzing outputs of the instrumented seat and the motion module to provide indications of applied force and relative motion. The invention also relates to a specific motion module/digitizer combination which can be used as a part of the knee laxity evaluator, or which can be used independently or in alternate systems. The invention also relates to a novel dynamometer for use in the knee laxity evaluator which includes a triple beam arrangement.



*Fig. 2*

The invention relates to a novel knee laxity evaluator (KLE) system.

The invention also relates to a motion module/digitizer  
5 combination which can be used in the KLE, or which can be  
used independently or in other systems. More specifically,  
the invention relates to such a combination which can  
measure, in three dimensional space, and relative to the  
position of a first point or body or coordinate system,  
10 position or motion of a second point or body, as well as  
position or motion of the second point or body relative  
to a third, fourth, fifth ... nth points, or positions  
of the second body, or combinations thereof.

15 Currently, the practice of measuring knee laxity is limited to a subjective evaluation by a physician of relative displacements at the knee. Through such an examination, damage to ligaments could be ascertained as a function of excess laxity or joint movement during passive loading  
20 by the physician. The limitations of this technique are :  
(a) a high level of subjectivity; (b) no quantitative or reproducible results; (c) no knowledge of applied forces; and (d) there are complicated motions which cannot be evaluated by human feel alone and hence there is important  
25 information being lost.

In accordance with the present invention, a KLE includes a motion module, that is, a module for measuring, in three dimensional space, movement of a point or body relative to  
30 a fixed point or body. Modules of this type are known in the art as is illustrated, for example, in U.S. Patent 3 944 798, Eaton, March 16, 1976, U.S. Patent 4 057 806, Furnadjiev et al, November 8, 1977, and U.S. Patent 4 205 308, Haley et al, May 27, 1980.

Electrical and electronic digitizers are also known in the art. For example, a two dimensional digitizer is illustrated in U.S. Patent 3 956 588, Whetstone et al, May 11, 1976.

5

However, there are no teachings in the art for combining the first systems, usually referred to as motion modules, and digitizers, whereby it is possible to measure the position or motion of a second point or body relative to the position of a first point or body and also relative to third, fourth, fifth ... nth points or positions of the second body or combinations thereof.

It is therefore an object of the invention to provide a novel knee laxity evaluator system.

It is a further object of the invention to provide a knee laxity evaluator system which uses a motion module.

It is a still further object of the invention to provide a combined electronic motion module/digitizer combination which can be used in the KLE or which can be used independently or in other systems.

It is a still further object of the invention to provide a novel dynamometer which can be used in the KLE or which can be used independently.

It is a more specific object of the invention to provide such a combination which will measure, in three dimensional space, and relative to the position of a first point or body, position or motion of a second point or body as well as position or motion of the second point or body relative to the third, fourth, fifth ... nth points, or positions of the second body or combinations thereof.

In accordance with a particular embodiment of the invention, a knee laxity evaluator comprises an instrumented seat for seating a patient and restraint means for restraining a portion of the patient to the instrumented  
5 seat whereby to measure forces applied to the patient at an unrestrained part thereof. Motion module means measure the motion of the unrestrained part of the patient relative to the restrained part thereof, and processor means analyze outputs of the instrumented seat and the motion  
10 module means and provide indications of applied force and motion of the unrestrained part relative to the restrained part.

From a different aspect, and in accordance with the invention, a motion module/digitizer combination comprises an  
15 elongated member having a first end and a second end and comprising a first link arm and a second link arm and means movably connecting the first link arm to the second link arm so as to permit translation motion between the  
20 first end and the second end, the means for connecting being disposed intermediate the first and second ends, the means also including first transducer means for measuring the translational motion. First mounting means are provided at the first end for mounting the first end at a first  
25 point, body or coordinate system and second mounting means are provided at the second end for mounting the second end at a second point or body. Second transducer means are provided at the first end for measuring three dimensional rotational motion of the first link arm relative to the  
30 first point or body and a third transducer means is provided at the second end for measuring three dimensional rotational motion of the second link arm relative to the second point or body. In accordance with the invention, a portion of the second link arm is detachable from the remainder  
35 of the second link arm and the second mounting means and

means are connectable to the remainder of the second link arm. Whereby, the combination of the first link arm, the remainder of the second link arm, and the means connectable, can be used to measure the position in space of  
5 third, fourth, fifth ... nth points or combinations thereof. And whereby, when the remainder of the link arm is reattached to the portion of the second link arm and the second mounting means, measurements can be performed to determine the position in space of the second point or  
10 body relative to the position of the first point or body or the position in space of the second point or body relative to the third, fourth, fifth ... nth points or positions of the second body or combinations thereof.

15 From a still different aspect, and in accordance with the invention, there is provided a dynamometer for determining the magnitude and direction of an applied force. The dynamometer includes three spaced beams and support means on each of the beams. Platform means are disposed on and  
20 supported by the support means for receiving and being deflected by the applied force. The deflection of the platform is transmitted to the beams to cause deflection of the beams. Means are provided for measuring the deflection of the beams in two directions thereof. In accordance with the invention, the beams are arranged such  
25 that no two redundant directions of deflection of the beams are permissible.

The invention will be better understood by an examination  
30 of the following description, together with the accompanying drawings, in which :

Figure 1 is a three dimensional view of a patient, with KLE attached, being examined by a physician.

Figure 2 is a side view of the patient.

Figure 3 is a more detailed side view of the patient.

5 Figure 4 is a front view of the leg showing motion/module digitizer attachment.

Figure 5 is a rear view of the leg showing the electrogoniometer attachment.

10

Figure 6 is a front view of an electronic motion module/digitizer combination in accordance with the invention.

Figure 7 is a side view of the combination.

15

Figure 8 illustrates examples of inserts.

Figure 9 is a flow chart of software for processing the electrical outputs of the combination to achieve the  
20 desired results.

Figure 10 illustrates a dynanometer in accordance with a further aspect of the invention; and

25 Figure 11 illustrates in greater detail one of the beams of the inventive dynanometer.

Turning first to Figures 1 to 5, there is illustrated a patient 1 having a KLE attached and being examined by a  
30 physician 3. The KLE system includes a thigh restraint means 7, an instrumented seat 9 and a motion module 11. The motion module is connected at one end 13 to the instrumented seat which, as will be seen below, constitutes a fixed point or body. The other end 15 is connected to a  
35 second point or body. The purpose of the instrument is to

determine the movement of the second point or body relative to the first point or body in three dimensional space.

- 5 The instrumented seat may be mounted on an examining table 17 and consists of a dynamometer 19 which measures applied forces. Instruments for measuring force are described in MEASUREMENT SYSTEMS : APPLICATION AND DESIGN by E. O. Doebelin, McGraw Hill, pps. 333-350. The instru-  
10 mented seat may also have an adjustable seat back arrangement 18 as is well known in the art.

The thigh restraint 7 comprises two or more pairs of off-set straps, which are fastened to each other by faste-  
15 ning means 8, and which displace soft tissue and may also provide a torquing of the tissue about the femur in order to minimize movement of the femur relative to the seat.

The lower leg attachment, illustrated best in Figures 4  
20 and 5, comprises a strap member 21, for example a velcro strap on which is carried the attachment 15a for the end 15 of the motion module. The lower leg attachment functions by referencing the motion module to three bony prominences of the lower leg, namely, the tibial crest 23  
25 and the medial and lateral malleoli, 25 and 27 respectively. Rollers 29 align themselves to the bony contours of the tibial crest, and balls in malleolar cups 31 do the same at the malleoli. These balls and rollers allow the skin to move between the attachment of the bone so that  
30 the attachment will move only with the bone which is important in attaining a true bone position measurement.

The system also includes a microprocessor based monitor 33  
which receives outputs from the dynamometer and the motion  
35 module. Thus, the KLE is capable of sensing and measuring

applied loads of displacements existing during the use of all standard knee evaluation techniques. In addition, the present KLE is designed to minimize the effects of soft tissue while still permitting the physician to hold, 5 palpate and manipulate the joint as in normal procedures while the KLE provides accurate applied force and tibial-femoral motion readings in displayed and printed form.

The dynamometer force plate measures forces and moments 10 in basic directions and permits the physician to know exactly to what levels the knee is being stressed. This is important when measuring laxity since the amount of relative bone motion depends on the stress applied. Knowledge of the forces is of utmost importance to the objec- 15 tive interpretation of joint laxity.

The motion module measures the true three dimensional position of the tibia relative to the seat, and hence, as the thigh is restrained, to the femur.

20

The motion module is an electromechanical device which functions on the principle that at least six measurements are required to totally define the position of an object in space as will be further discussed below. It will 25 consist of a means capable of measuring six degrees of freedom, three dimensional motion of one point or body relative to another point or body and preferably comprises a unique arrangement of electronic components capable of measuring rotational or translational displacements. A 30 specific module is described below in association with Figures 6 to 8. Generally speaking, the two points or bodies between which relative motions are being measured are connected by a single rigid telescopic arm, or a single arm having a joint between its two ends.



The force measurement on the dynanometer is accomplished through the principles of opposite and equal reaction forces. The forces applied to the knee of the patient are reacted to by the femur and thigh which are in turn transmitted to the dynanometer. Inasmuch as the forces are of a different arrangement in the dynanometer as compared to the knee, knowledge of the relative position of the knee and the dynanometer, provided by the motion module, permits a theoretical interpretation of the forces and their representation in the coordinate system of the knee.

In operation, a patient is seated in the instrumented seat and the thigh of the leg of interest is restrained as shown in Figure 1. The lower leg attachment is then mounted on the same leg as illustrated in the drawings, and the motion module is connected between the seat and the lower leg attachments. The physician can then twist the lower leg, and he will receive outputs indicating relative displacement as well as force applied.

Turning now to Figures 6 to 8, there is illustrated a particular motion module/digitizer combination which can be used in the KLE environment. However, as also mentioned, the combination can be used in other systems or it can be used independently. For example, it could be used in association with machine tools and other mechanical systems where it is necessary to be able to measure displacement of a first point or body relative to a second point or body.

To measure the motion of a body in three dimensional space, six unique measurements are required relating to the six degrees of freedom of motion in three dimensional space. The measurements can constitute six unique rotational measurements or six unique translational measurements or combinations thereof, i. e., four rotational and two

translational, etc. The combination in accordance with the invention takes five unique measurements of rotational motion and one measurement of translational motion.

5 Referring now to Figures 6 and 7, the combination includes an elongated member 101 having a first end 103 and a second end 105. The elongated member comprises a first link arm 107 and a second link arm 109. The link arms 107 and 109 are joined together at 111 to permit relative  
10 translational movement as between 103 and 105 and to measure this translational movement. In the embodiments illustrated, the link arms are connected for pivotal motion whereby to permit relative translational motion of 103 and 105, and a rotary transducer means is used to mea-  
15 sure this translational motion as will be discussed below.

As will be obvious, other means could be used for so connecting arms 107 and 109. For example, one of the arms could include a sleeve for overlying the other arm and  
20 for permitting movement of the other arm into and out of the sleeve. A translational transducer means could be included in the sleeve for measuring the translational motion.

25 Examples of rotary transducer means which can be used are resistive potentiometers, variable inductance transformers, synchro resolvers, inductance potentiometers and variable reluctance transducers. Examples of translational trans-  
30 ducers which could be used are dial indicators, resistive potentiometers, variable inductance transformers, capacitance transducers, piezoelectric transducers, ionization transducers and optical transducers.

In describing the illustrated embodiment, rotary and trans-  
35 lational potentiometers, respectively, are utilized.

Accordingly, these will be henceforth referred to. However, it is to be understood that such translational and rotary potentiometers could be replaced by respective ones of the above-mentioned transducers.

5

Disposed at the end 103 is a first rotary potentiometer 113 which is disposed in line with the arm 103 and rotatable about an axis at right angles to the arm 103. A second rotary potentiometer 115 is disposed at right angles to the potentiometer 113 and is rotatable about an axis at right angles to the axis of the potentiometer 113. Potentiometer 115 is mounted on mounting block 117 for mounting the arrangement at one end thereof.

15 Disposed at second end 105 is a third rotary potentiometer 119 which is in line with the second link arm 109 and which rotates about an axis at right angles to the second link arm 109. A fourth rotary potentiometer 121 is disposed at right angles to potentiometer 119 and is rotatable about an axis at right angles to the axis of potentiometer 119. A fifth rotary potentiometer 123 is also disposed at right angles to potentiometer 119 and is rotatable about an axis at right angles to the axis of potentiometer 119. Potentiometer 123 is also at right angles to potentiometer 25 121 and its axis of rotation is also at right angles to the axis of potentiometer 121.

Potentiometer 123 is connected to mounting block 25 for mounting the arrangement at a second point.

30

In the illustrated embodiment, arms 107 and 109 are connected at 111 by a sixth rotary potentiometer 127 which is in line with both arms 107 and 109 and whose axis of rotation is at right angles to both arms 107 and 109.

The arrangement as thus far described can measure the motion in three dimensional space of end 105 relative to end 103 or vice-versa and is referred to as motion module. In accordance with the invention, there is provided the potential for digitizing the positions of third, fourth, fifth ... nth points or bodies (henceforth, the use of the term points will be used and understood to refer to points or bodies) in three dimensional space, or combinations thereof, and of then measuring the motion or position of one of the points 103 or 105 relative to the position of the other point or relative to the third, fourth, fifth ... nth points, or positions of the second body, or combinations thereof. This potential is achieved by making one of the link arms disconnectable from its respective mounting block and reconnectable again thereto. In the illustrated embodiment, link arm 109 is disconnectable from mounting block 125. Specifically, the protrusion 129 which extends from potentiometer 119 is insertable into a receptacle 131. The protrusion is also removable from the receptacle, and other inserts, such as those illustrated in Figures 8A, 8B, etc. can be inserted into the receptacle for digitizing the positions of other points in space.

For an understanding as to how the combination operates, we will take the intersection of the axes of potentiometers 113 and 115 as the global origin O. Thus, potentiometers 113, 115 and 127 define a spherical coordinate system about O. Specifically, potentiometers 113 and 115 provide the conventional angles  $\theta$  and  $\phi$  respectively, while the potentiometer 127, combined with 107 and 109, provide the length of the vector R. (Knowing the length of 107 and 109, and knowing the angle therebetween, it is quite easy to determine the length of the vector R). Point B is defined as the intersection of the axes of potentiometers

119, 121 and 123 and is considered the origin of the "moving body" coordinate system. In distinction thereto, 0 is considered to origin of a "fixed" body or coordinate system. Specifically, mounting block 125 would be mounted  
5 on a moving body. Mounting block 117 would be mounted on the fixed body or coordinate system, and the measurement of the movement of 105 relative to 103 would define the motion of the moving body relative to the fixed body or coordinate system.

10

The final description of the moving body motion is contained in the three finite rotations provided by the potentiometers 119, 121 and 123.

15 To illustrate how the combination is used as a digitizer, the protrusion 119 is removed from the receptacle 131, and one of the digitizer tips illustrated in Figure 8 is inserted into the receptacle in place of the protrusion 119. The tip is then pointed at points of interest, name-  
20 ly, a third, fourth, fifth ... nth points above-mentioned, and a reading is taken of the three dimensional position in space of these points.

As will be understood, conductive leads from the poten-  
25 tiometers will be brought to a connecting board, which could be disposed on the mounting blocks 117, so that the electrical signals developed at the potentiometers can be brought to a processing means such as the processing means illustrated schematically at 133 in Figure 1. It will, of  
30 course, be necessary to provide DC power to the potentiometer to measure the changing resistance thereof, as well known in the art, and this DC power could also be provided from the processing means 133.

35 The potentiometers will provide the data for determining

the extent and direction of the motion of point 105. In order to determine the direction and extent, the data must be processed. Preferably, the data is processed by computer means. A flow chart for controlling such a computer is illustrated in Figure 8.

Three basic subroutines are employed in digitization, two of which are illustrated in the flow chart. The DIGMAT (digitization transformation matrix) and DIGIT (digitization) are shown in the flow chart while NEWTIP (support routine for user defined tip) must be provided by the user and takes into account the dimensions and shape of the user supplied tip.

While the user must write a program employing the subroutines in a manner appropriate to his specific application, in all cases the following procedure must be used.

The protrusion 129 is removed from the receptacle 131, and one of a variety of tips is inserted in the receptacle. The mounting blocks 117 must be firmly mounted at a position which both permits easy access to most points of interest and is also appropriate for any subsequent motion measurement using both upper and lower components of the motion module. A position of interest is then pointed at with the tip.

The physical characteristics are inputted into the computer memory, and a code is then presented to the computer to let it know which of the tips is being used.

Upon pointing at the position with the tip, the program must be activated either through a remote switch or a keyboard entry. The control program will then scan the signals in the potentiometer, and then in sequence, call

the subroutine DIGMAT, which uses as input the voltage values of potentiometers 113, 115 and 127, as well as the voltage of the power supply. DIGMAT outputs to transformation matrices which are used in the subroutine digit  
5 which is the next subroutine to be called. DIGIT actually computes the position of DTIP in the global coordinate system using as input the output of DIGMAT and DTIP coordinates in potentiometer 127 coordinate system.

10 An output is then provided of the points in the global coordinate system, that is, relative to the point 0.

This procedure is repeated until all of the points of interest have been digitized. The TIP is then removed  
15 from the receptacle 131 and the protrusion 129 is again inserted in the receptacle. The subroutine LOCTRN, which computes the coordinates of the digitized points in the local coordinate system (that is, with the point B as an origin) is then called. These points are then outputted  
20 to the GLOTRN subroutine which will be discussed below.

In the meantime, the mounting block 125 would have been attached to the point of interest. Displacements of this point are performed, and the potentiometer signals are  
25 once again scanned. This data is communicated to the computer and the subroutine DISMAT is called. DISMAT computes the contents of the transformation matrix describing the body in three dimensional space. The subroutine GLOTRN is then called and outputs new positions of  
30 those points previously digitized on the body or analytically generated points, in the global system. This procedure continues as the point of interest moves through different positions.

35 The following are the technical specifications of the

subroutines :

SUBROUTINE DIGMAT (DVOL, DT12, DT3)

5 DESCRIPTION :

This subroutine computes matrix DT12 as well as matrix DT3 which locates the position of potentiometer-113 and potentiometer-127 coordinate systems, respectively.

10

These two matrices are strictly inputs to subroutines DIGIT and NEWTIP, and have no significance to the user.

INPUT

15

-DVOL (4), voltages of potentiometers-115, 113 and 127, and the power supply, respectively. (Note 1)

20

OUTPUT

- DT12 (3,3) and DT3 (3,3) are the above-mentioned matrices. (Note 1)

25

NOTE

1-all the variable names starting with D in each subroutine, are double precision.

30

SUBROUTINE DIGIT (DT12, DT3, DTIP, DPNTRF)

DESCRIPTION :

This subroutine computes the coordinates of the digitizer tip with respect to the global coordinate system.

35



INPUT

- 5       -DT12 (3,3), and DT3 (3,3) locate the position  
          of potentiometer-113 and potentiometer-127  
          coordinate systems, respectively. (Refer to  
          subroutine DIGMAT). (Note 3)
- 10       -DTIP (3) are the coordinates of the tip in use with  
          respect to the potentiometer-127 coordinate system.  
          (Note 1, 2 & 3)

OUTPUT

- 15       -DPNTRF (3) are the coordinates of the tip with  
          respect to the global coordinate system.  
          (Note 2 & 3)

NOTES

- 20       1-The coordinates of the digitizer tips are  
          provided as part of the Digitizer Unit.  
          For the coordinates of User tip, use subroutine  
          NEWTIP. (Refer to subroutine NEWTIP)
- 25       2-In all coordinate arrays 1, 2 & 3 are X, Y  
          and Z coordinates, respectively.  
          (e.g. DTIP(1) = X coordinate)
- 3-All variable names starting with D are in  
          double precision.

30   SUBROUTINE NEWTIP (DT12, DT3, DPNTRF, DTIP)

DESCRIPTION :

35   The main purpose of this subroutine is to define the coor-  
      dinates of any user-designed tip with respect to

potentiometer-127 coordinate system without independently measuring the tip dimensions. In order to find the tip constants, first mount tip number 1 (see 8b) and touch a point (Note 1). Then mount the new tip and touch the same point. Through the software the coordinates of the point are computed by tip  $\neq$  1 and are used to compute the constants for the new tip.  
(Refer to the Control Program Flow Chart).

10     NOTES

1-For best results, use a point within 6 to 8 inches from the base of the digitizer.

15     INPUT

- DT12 (3,3), and DT3 (3,3) locate the position of potentiometer-113 and potentiometer-127 coordinate systems, respectively. (Note 1)

20

- DPNTRF(3) : coordinates of the digitized point by tip  $\neq$  1 with respect to global coordinate system. (Note 1 & 2).

25     OUTPUT

- DTIP(3) : coordinates of the tip with respect to potentiometer-127 coordinate system, or better known as the new tip constants. (Note 1 & 2)

30     NOTES

1-All variable names starting with D are double precision.

2-In the coordinate system arrays 1, 2 & 3 are X, Y and Z coordinates, respectively.

SUBROUTINE DISMAT (DVOL, DMAT2)DESCRIPTION :

5 DISMAT computes the position of the local coordinate system with respect to the global coordinate system. The local coordinate system is in line with indicated edges of upper mounting block.

10 INPUT

- DVOL(7) voltage readings of potentiometers-113, 127, 115, 119, 121, 123 and the power supply line, respectively. (Note 1)

15

OUTPUT

- DMAT2 (4,3) consists of :  
DMAT2 (4,1), DMAT2 (4,2) and DMAT2 (4,3) are  
20 the coordinates of point B in global coordinate system.  
DMAT2 (3,3) defines the position of the local coordinate system with respect to the global coordinate system. (Note 1)  
25 DMAT2 (4,3) is input only to subroutines LOCTRN and GLOTRN, and has no significance to the user.

NOTE

30

1-All variable names starting with D are double precision.

SUBROUTINE LOCTRN (DMAT2, DPOINT, DPNTLC, N)DESCRIPTION :

- 5 LOCTRN computes the coordinates of the digitized points  
in local coordinate system.

These coordinates are constant as long as the upper mounting block is fixed to the bone or some other chosen  
10 mounting base.

If the upper mounting block is shifted these coordinates should be computed again by calling subroutine LOCTRN.  
(Refer to the Control Program Flow Chart)

15

INPUT

- DMAT2 (4,3), from subroutine DISMAT  
(refer to subroutine DISMAT). (Note 1)
- 20 - N is number of points; integer.
- DPOINT (3,N) : coordinates of the digitized  
and analytical points in the global coordinate  
25 system. (Note 1 & 2)

OUTPUT

- DPNTLC (3,N) coordinates of the points with  
30 respect to the local coordinate system.  
(Note 1 & 2)

NOTE

- 1-All variable names starting with D are  
35 double precision.

2-In the coordinate arrays 1, 2 and 3 are  
X, Y and Z coordinates, respectively.

SUBROUTINE GLOTRN (DAMT2, DPNTLC, DPNTGL, N)

5

DESCRIPTION :

GLOTRN computes the new coordinates of the points in the  
global coordinate system.

10

INPUT

-DMAT 2 (4,3), from subroutine DISMAT  
(refer to subroutine DISMAT). (Note 1)

15

-N number of points; integer.

-DPNTLC (3,N) : coordinates of the points in local  
coordinate system. (Note 1 & 2)

OUTPUT

20

- DPNTGL (3,N) new coordinates of the points  
in global coordinate system. (Note 1 & 2)

NOTES

25

1-All variable names starting with D are  
double precision.

2-In the coordinate arrays 1, 2 and 3 are  
X, Y and Z coordinates, respectively.

30

Although reference was made to dynanometers above, in  
accordance with a further aspect of the invention, there  
is provided a novel dynanometer, comprising a triple beam  
support system, illustrated in Figures 10 and 11 hereof.

35 As seen in these Figures, the dynanometer comprises a

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supporting frame 201 which, in the illustrated embodiment, comprises a four walled structure. Disposed centrally of one wall is a first spherical or rectangular beam 203. Second and third rectangular or spherical beams 205 and 207 are disposed in the corners opposite the wall of the 203 beam.

As seen in Figure 11, each beam comprises a vertical support portion 209 and horizontal deflection member 211. The vertical and horizontal members are joined by spherical/linear bearings 213. The bearings are the key to the proper operation of this triple beam system since they release all moments at the beams permitting the moments to be measured at various beams through their respective bending deflections, rather than being lost as axial beam compression or pure moments.

The beams are arranged such that the longitudinal axis of each deflection member 211 is the perpendicular bisector of a respective side of an equilateral triangle. This particular arrangement is convenient for subsequent analyses.

Supported at the top surfaces of the vertical members is a platform 215. The platform can be of any convenient shape, so long as it is supported by the top surfaces of the vertical members. In the illustrated embodiment, the platform 215 forms an equilateral triangle, and a beam is disposed at each corner of the triangle. The horizontal member of the beam is perpendicular to the side of the triangle opposite its corner.

Forces are measured by their application through the platform 215. These forces result in the deflection of the beams. The deflections are measured as an indicator of the forces.

Although in the illustrated embodiment the beams are at the corners of an equilateral triangle, any arrangement of three beams where there are no two redundant directions of deflections are permissible for two reasons :

5

- a) Such an arrangement will provide a rigid mechanical mechanism; and
- b) The minimum of six non-redundant forces required for the solution of the equilibrium equations will be measured.

10

Devices, illustrated schematically at 217 and 219 with respect to beam 203, 221, 223 with respect to beam 207 and 225, 227 with respect to beam 205 are used to measure the deflection of the beams. The devices can comprise conventional displacement transducer devices and they would be mounted onto the rigid support frame and in such a manner that deflections in only the two planes of interest are measured for each beam. The resulting force measurements would be the minimum required to fully define all the external forces and moments acting on the platform. The necessary formulations for equilibrium of rigid body are the subject of numerous engineering text.

15

20

25 Conventional displacement transducers which can comprise the items 217 to 227 are :

- Capacitance gauge
- Linear variable differential transformer
- (LVDT)
- Hall effect detector
- Reflected/interrupted light intensity
- Rectilinear potentiometer.

30

35 With the set-up as illustrated, the deflections for each

- beam will be resolved in two directions through each beam. One direction is parallel to the axis of the vertical member and consists of the forces labelled F2, F4, F6, and the other direction is perpendicular to the first direction as illustrated by the arrows labelled F1, F3 and F5. The devices 217, 221 and 227 measure the forces in the direction F2, F4 and F6, while the devices 217, 223 and 225 measure the forces in the direction F1, F3 and F5.
- 10 When a force is applied to the platform 215, depending on the magnitude of the force and the direction of the application thereof, the beams 203, 205 and 207 will be deflected by different amounts. The magnitudes of deflection are resolved in the two directions as above-described, and the magnitudes in the respective directions are measured by the devices 217 to 227. Using this technology and wellknown mathematical vector transformations, the force applied at the platform can be calculated.
- 20 Although particular embodiments have been described, this was for the purpose of illustrating but not limiting the invention. Various modifications, which will come readily to the mind of one skilled in the art, are within the scope of the invention as defined in the appended
- 25 claims.



CLAIMS :

1. A knee laxity evaluator (KLE) comprising :
  - a) an instrumented seat for seating a patient;
  - 5 b) restraint means for restraining a portion of the patient to said instrumented seat whereby to measure forces applied to said patient at an unrestrained part thereof;
  - 10 c) motion module means for measuring the motion of said unrestrained part of said patient relative to the restrained part thereof; and
  - 15 d) processor means for analyzing outputs of said instrumented seat and said motion module means and for providing indications of applied force and motion of said unrestrained part relative to said restrained part.
2. A KLE as defined in claim 1 wherein said instrumented seat comprises a dynamometer.
- 20 3. A KLE as defined in claim 2 wherein said restraint means comprises strap means and wherein said restraint portion comprises the thigh of the patient;  
said unrestrained portion comprising the lower leg of  
25 the restrained thigh or upper leg of the patient.
4. A KLE as defined in claim 3 wherein said motion module means comprises a motion module/digitizer for determining the position in space of specific points of interest on  
30 the lower leg, and for measuring the position and motion of the specific points relative to the position of said thigh or upper leg.
5. A KLE as defined in claim 4 wherein said strap means  
35 comprises a plurality of pairs of off-set straps, wrapable

around said thigh or upper leg, and means for fastening the pairs of straps to each other.

6. A KLE as defined in claim 5 wherein an end of said motion module means is attached to said lower leg by attachment means comprising;

a strap member attachable around said lower leg in the area of the tibial crest thereof;

rollers for aligning themselves on the bony contours of said tibial crest;

malleolar cups mounted on the medial and lateral malleoli of said lower legs; and

balls in said malleolar cups for aligning a respective one of said cups on a respective one of said medial and lateral malleoli.

7. A KLE as defined in claim 6 wherein said motion module means comprises means for measuring in three dimension space using six unique measurements relating to the six degrees of motion in three dimension space.

8. A KLE as defined in claim 3 wherein said motion module comprises an elongated member having a first end and a second end;

said first end being connected to said instrumented seat;

said second end being connected to the bottom leg of said restrained thigh of said patient.

9. A motion module/digitizer combination comprising :

an elongated member having a first end and a second end and comprising a first link arm and a second link arm and means movably connecting said first link arm to said second link arm so as to permit translational motion between said

first end and said second end, said means for connecting

being disposed intermediate said first and second ends,  
said means also including first transducer means for  
measuring said translational motion;

first mounting means at said first end for mounting  
5 said first end at a first point, body or coordinate  
system;

second mounting means at said second end for mounting  
said second end at a second point or body;

second transducer means at said first end for measuring  
10 three dimensional rotational motion of said first link  
arm relative to said first point or body;

third transducer means at said second end for measuring  
three dimensional rotational motion of said second link  
arm relative to said second point or body;

15 characterized in that a portion of said second link  
arm is detachable from the remainder of said second link  
arm and said second mounting means;

means connectable to the remainder of said second link  
arm;

20 whereby, the combination of said first link arm, the  
remainder of said second link arm, and said means connec-  
table, can be used to measure the position in space of  
third, fourth, fifth ... nth points or combinations  
thereof;

25 and whereby, when said remainder of said link arm is  
reattached to said portion of said second link arm and  
said second mounting means, measurements can be performed  
to determine the position or motion in space of said  
second point or body relative to the position of said  
30 first point, body or coordinate system or said third,  
fourth, fifth ... nth points, or positions of the second  
body, or combinations thereof.

10. A combination as defined in claim 9 wherein said first,  
35 second and third transducers comprise rotary transducers,

the rotational axis of said rotary transducers being at right angles to the longitudinal axes of adjacent ones of said links, the longitudinal axes of said links running through said centers of rotation.

5

11. A combination as defined in claim 10 and further including;

a fourth rotary transducer disposed at said first end at right angles to said second transducer;

10 the center of rotation of said fourth transducer being in line with the center of rotation of said second transducer.

12. A combination as defined in claim 11 and including a  
15 fifth rotary transducer at said second end at right angles to said third transducer;

the center of rotation of said fifth transducer being in line with the center of rotation of said third transducer;

20 a sixth rotary transducer at right angles to said third transducer and said fifth transducer;

the center of rotation of said sixth transducer and said third transducer being in line.

25 13. A combination as defined in claim 12 wherein said first mounting means is attached to said fourth transducer and wherein said second mounting means is attached to said sixth transducer.

30 14. A combination as defined in claim 13 and including a data processor;

conductive means leading from said first, second, third, fourth, fifth and sixth transducers to said data processor;

whereby signals from said transducers can be analyzed  
35 by said data processor.

15. A method for measuring the motion in three dimensional space, relative to the position of a first point, the position or motion of a second point, and of measuring the position or motion of the second point relative to  
5 third, fourth, fifth ... nth points, or positions of the second body, or combinations thereof using a motion module/digitizer arrangement which includes a motion module/digitizer combination comprising :

an elongated member having a first end and a second end  
10 and comprising a first link arm and a second link arm and means movably connecting said first link arm to said second link arm so as to permit translational motion between said first end and said second end, said means for connecting being disposed intermediate said first and second  
15 ends, said means also including first transducer means for measuring said translational motion;

first mounting means at said first end for mounting said first end at a first point, body or coordinate system;

second mounting means at said second end for mounting  
20 said second end at a second point or body;

second transducer means at said first end for measuring three dimensional rotational motion of said first link arm relative to said first point or body;

third transducer means at said second end for measuring  
25 three dimensional rotational motion of said second link arm relative to said second point or body;

characterized in that a portion of said second link arm is detachable from the remainder of said second link arm and said second mounting means;

30 means connectable to the remainder of said second link arm;

whereby, the combination of said first link arm, the remainder of said second link arm, and said means connectable, can be used to measure the position in space of  
35 third, fourth, fifth ... nth points or combinations thereof;

and whereby, when said remainder of said link arm is reattached to said portion of said second link arm and said second mounting means, measurements can be performed to determine the position or motion in space of said  
5 second point or body relative to the position of said first point or body or said third, fourth, fifth ... nth points, or positions of the second body, or combinations thereof;

said method comprising the steps of :

- 10 1) disconnecting the link arm to locate the positions in space of the third, fourth ...nth point or combinations thereof;
- 2) reconnecting said link arm to thereby monitor the movement of said second point or body relative to  
15 said first point or body and relative to said third, fourth ... nth points, or positions of the second body, or combinations thereof.

16. A dynamometer for determining the magnitude and direction of an applied force;

comprising :

three spaced beams;

support means on each of said beams;

platform means, disposed on and supported by said

- 25 support means, for receiving and being deflected by said applied force;

whereby deflection of said platform is transmitted to said beams to cause deflection of said beams; and

- 30 means for measuring the deflection of said beams in two directions thereof;

wherein said beams are arranged such that no two redundant directions of deflection of said beams are permissible.

- 35 17. A dynamometer as defined in claim 16 wherein each

said beam comprises; .

a vertical support member;

a horizontal deflection member;

spherical/linear bearings interposed between said

5 vertical and horizontal members;

said platform being disposed on the top surfaces of  
said vertical members;

said means for measuring the deflection of said horizontal members.

10

18. A dynamometer as defined in claim 17 wherein the means  
for measuring deflection comprises, for each said beam,  
a first measuring means for measuring the horizontal  
deflection of each beam; and

15 a second means for measuring the vertical deflection  
of each said beam.

19. A dynamometer as defined in claim 18 wherein the beams  
are arranged such that the longitudinal axis of each  
20 horizontal deflection member is the perpendicular bisector  
of a respective side of an equilateral triangle.

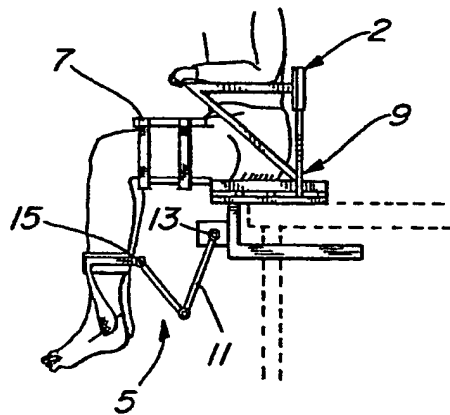
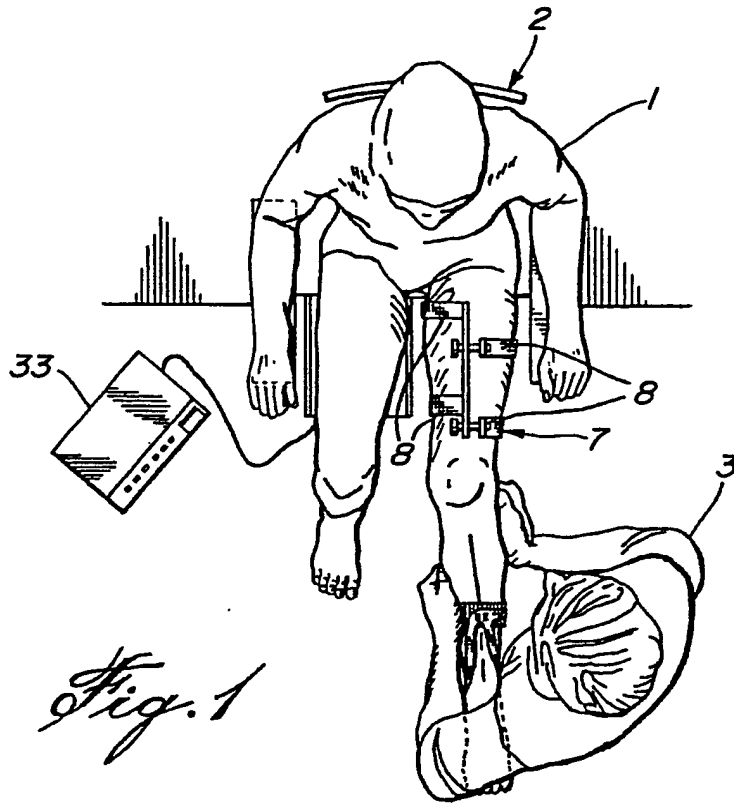
20. A dynamometer as defined in claim 19 and including  
a four walled square support frame;

25 one of said beams being mounted adjacent the center  
of one of the walls of the support frame;

the other two of the beams being mounted, respectively,  
adjacent supporting corners of said support frame opposing  
said one wall.

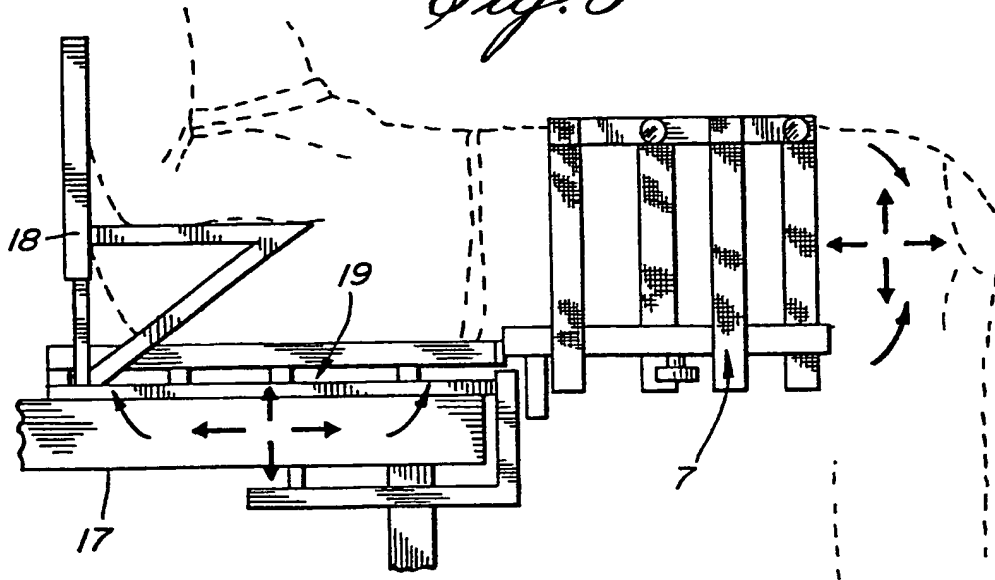
30

21. A dynamometer as defined in claim 20 wherein said means  
for measuring are selected from conventional displacement  
transducers comprising capacitance gauge, linear variable  
differential transformer, hall effect detector, reflected/  
35 interrupted light intensity or rectilinear potentiometer.

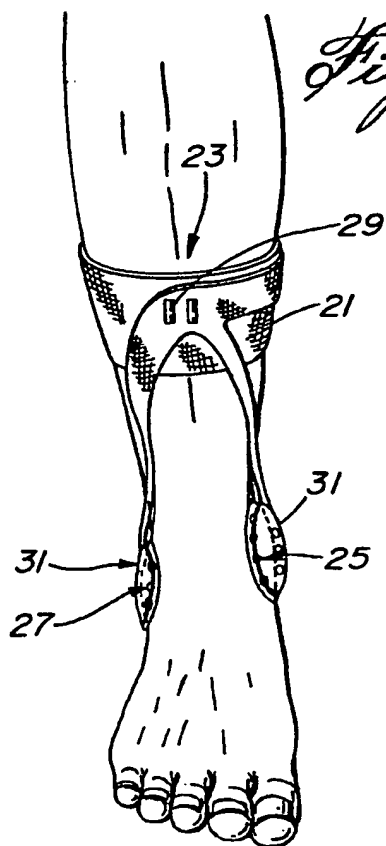




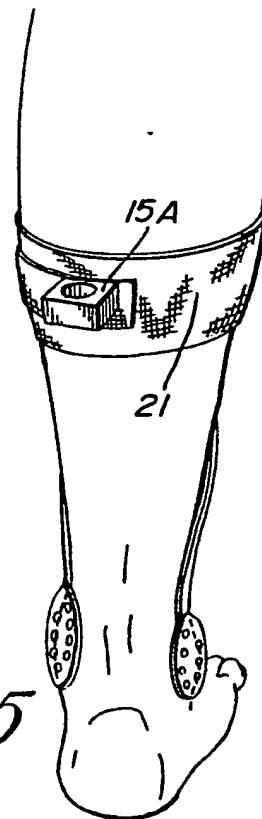
*Fig. 3*

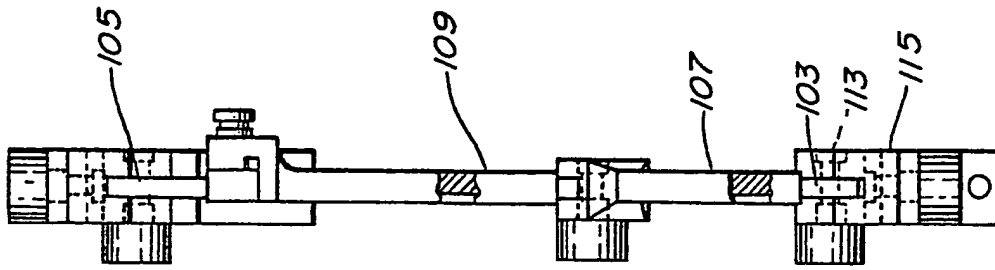


*Fig. 4*

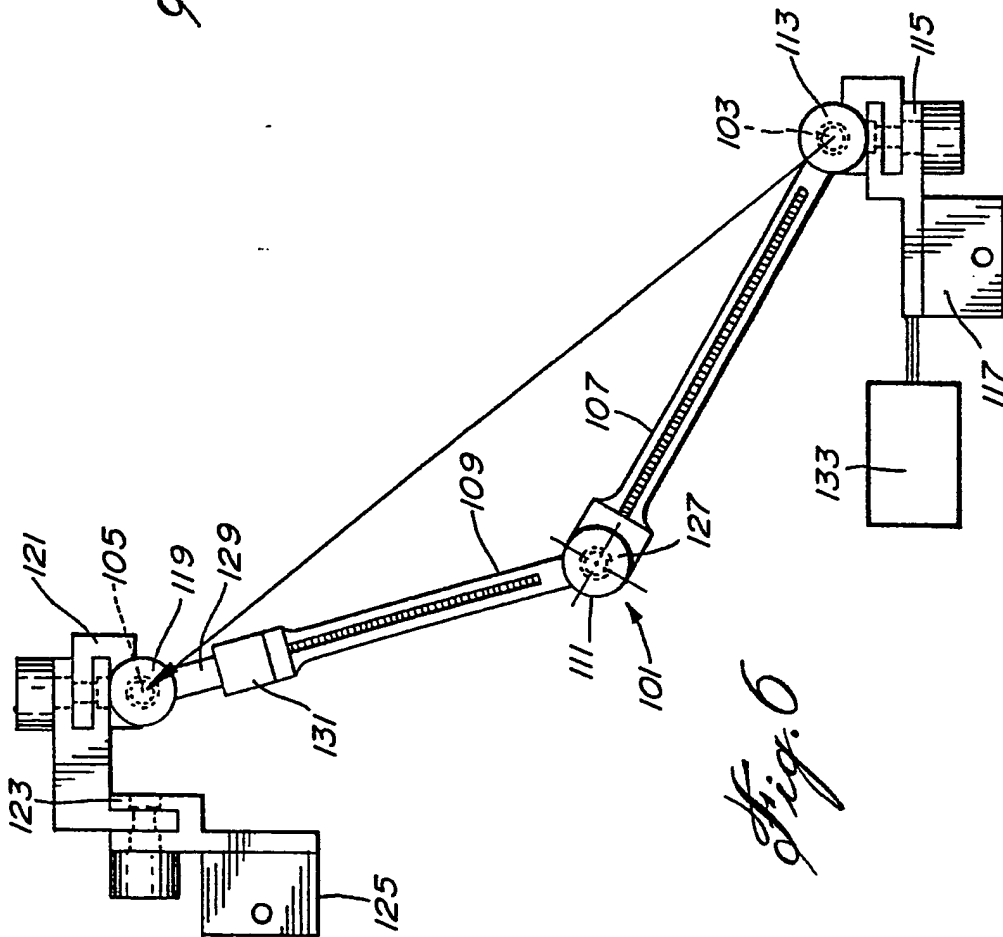


*Fig. 5*

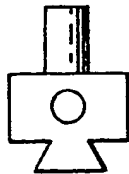




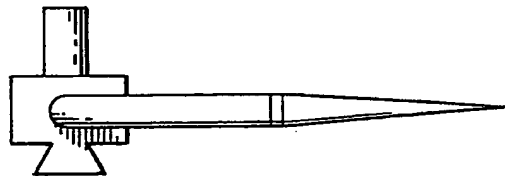
*Fig. 7*



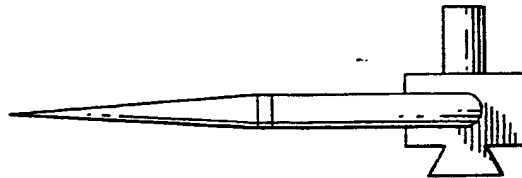
*Fig. 6*



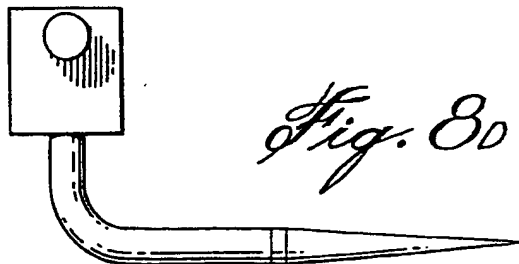
*Fig. 8A*



*Fig. 8B*

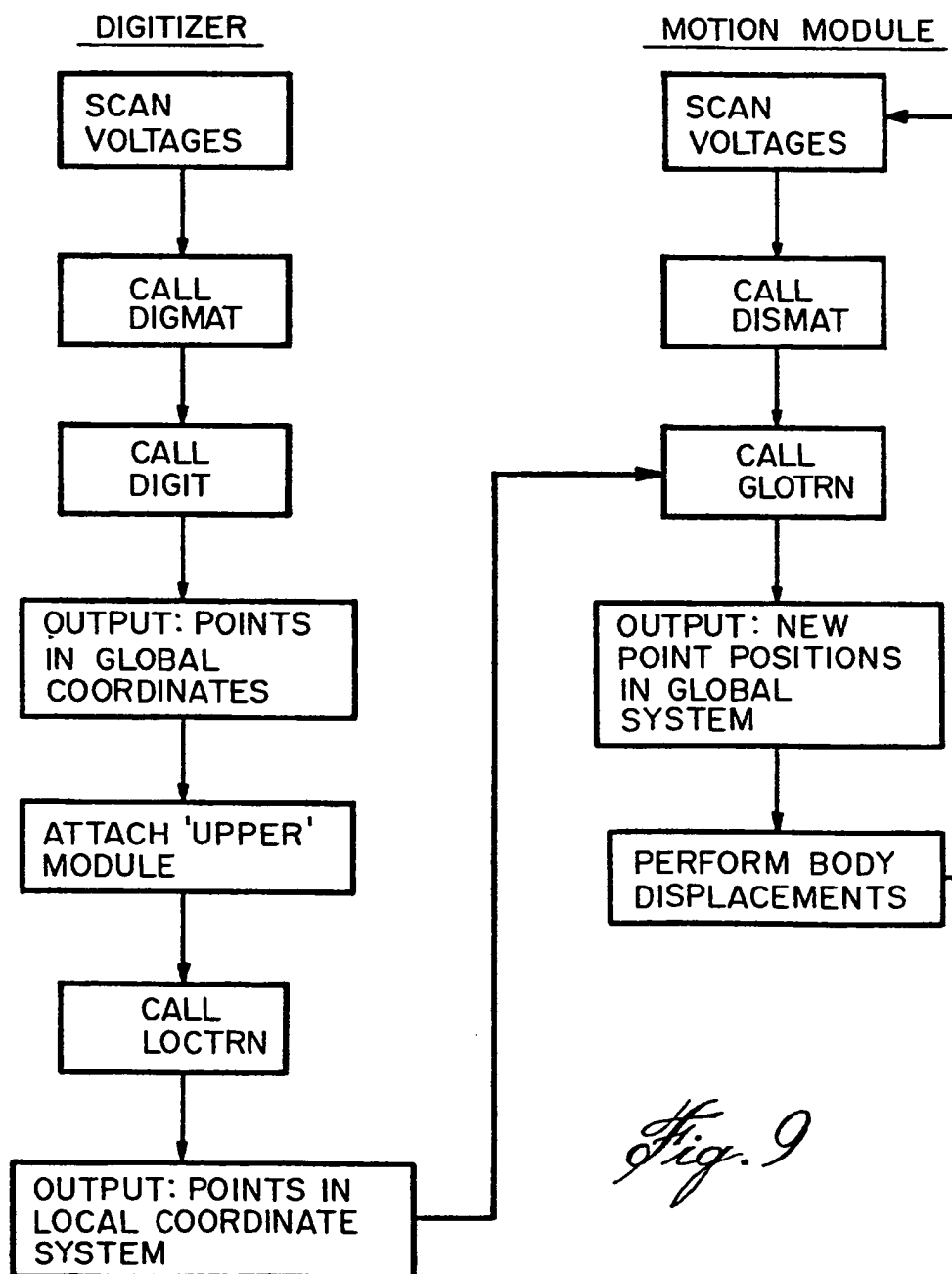


*Fig. 8C*



*Fig. 8D*

SIMPLIFIED OPERATIONS  
FLOW CHART (TYPICAL APPLICATION)



*Fig. 9*

